Fullerene derivative based spin-on-carbon hard masks for advanced lithographic applications

Conference or Workshop Item

Fullerene Derivative Based Spin-on-Carbon Hard Masks for Advanced Lithographic Applications

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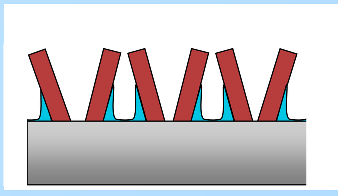
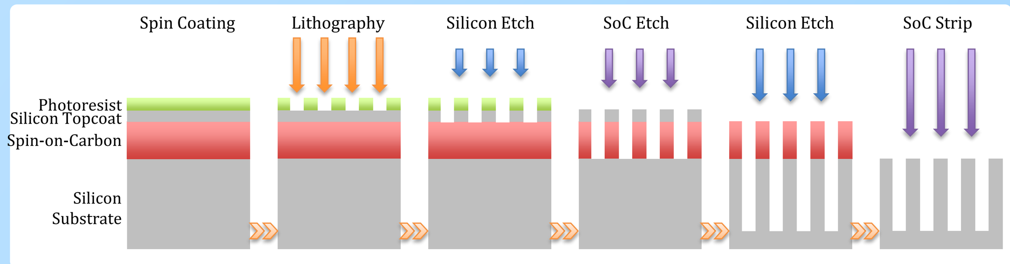
Introduction

The advance of lithographic resolution requires extremely thin photoresist films for the fabrication of '1x nm' structures to mitigate resist collapse during development, but the use of such thin films will limit achievable etch depths.



Pattern collapse due to aspect ratio

Multilayer hard mask stacks are a possible solution. We have developed a fullerene based spin-on carbon hard mask material capable of high aspect ratio etching.



Process flow of trilayer scheme

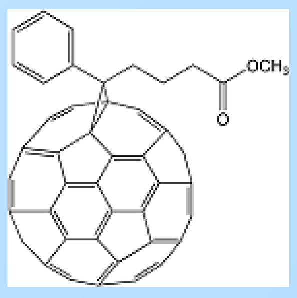
The high resolution image is captured in a thin resist top coat layer and transferred down through the stack to produce high aspect ratio carbon hard mask structures suitable for substrate etching.

Key hard mask properties

Key attributes for hard mask materials are

- Cost
- Spin coating from standard solvents
- Short bake durations
- High thermal stability
- Low etch rate in halogen plasmas
- High etch rate in oxygen plasmas
- High resolution patterning (20 nm or better)
- Low "wiggle" at sub-30 nm

Distortion, ("wiggling") of the features in the thick carbon layer during the final fluorine silicon etch step.
- can be a significant problem at smaller feature sizes.



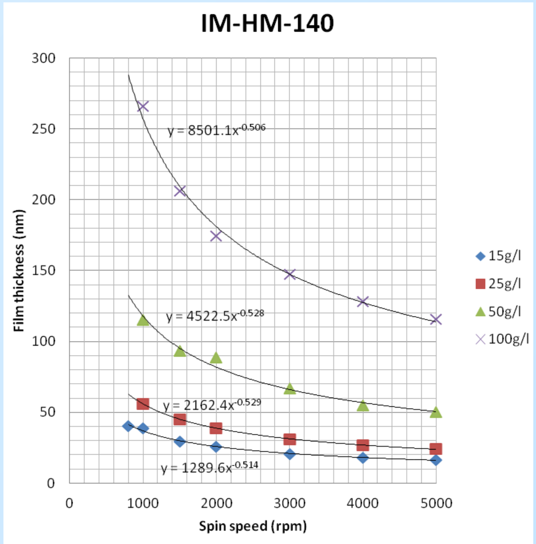
The etch resistance of the fullerene based material allows high-aspect ratio plasma etching from a very thin film and at high-resolution.

The materials have low levels of aliphatic hydrogen, which is proposed as a solution to the "wiggling" of features below 30nm during the plasma etch step to transfer of the features to the underlying layer.
- Wiggling is not observed with IM hard mask materials.

Fullerene hard mask

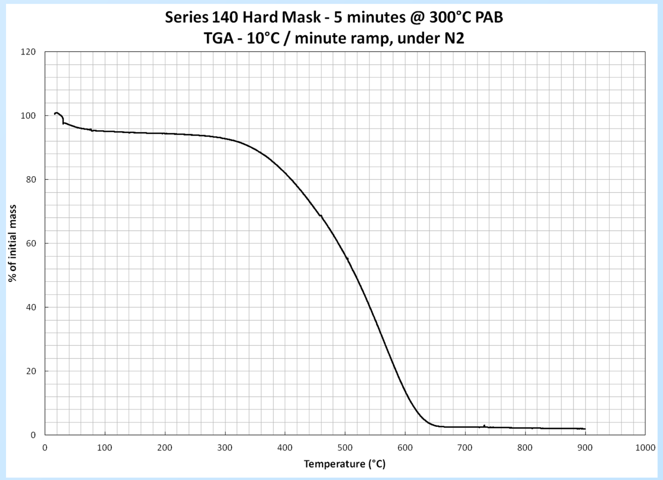
Fullerene derivatives are dissolved in cyclohexanone, mixed in equal parts with a crosslinker and spin coated onto silicon substrates.

After baking on a hotplate at 300˚C the material is rendered insoluble in common solvents.



Film thickness vs. spin speed curves for IM-HM-140 series

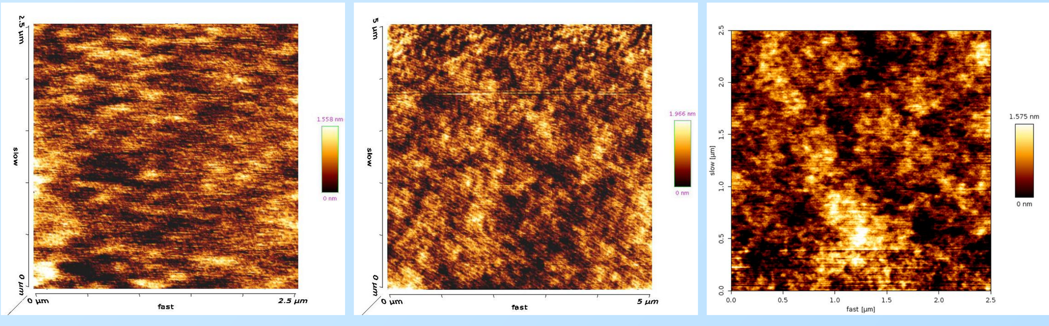
Thermal stability



Thermogravimetric analysis (TGA) shows the HM-140 fullerene based hard mask to have a high thermal stability, with a mass loss of only ~13.7% at 400˚C.

Mechanical Characterization

Measurements of surface roughness and mechanical characteristics performed by AFM and nanoindentation.

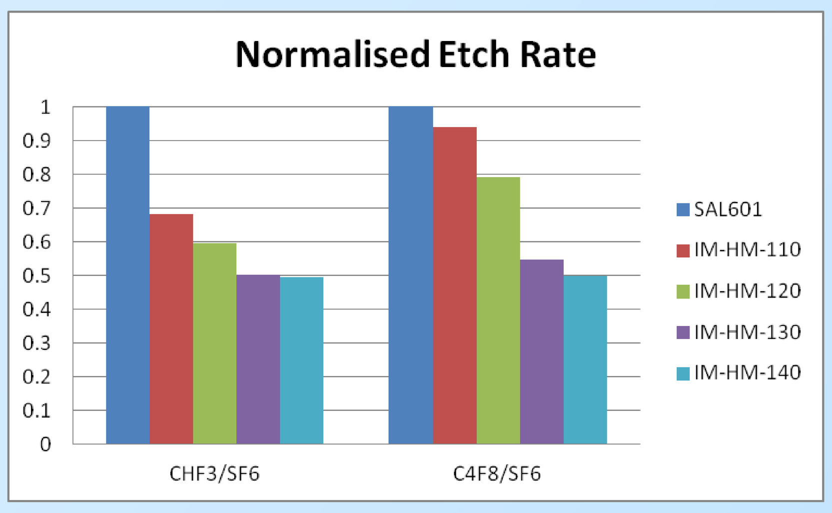


Bare silicon IM-HM-110 IM-HM-120

	Bare Silicon	IM-HM-110	IM-HM-120
Average Roughness	0.28 nm	0.36 nm	0.28 nm
RMS Roughness	0.35 nm	0.45 nm	0.36 nm
Peak to Valley	4.57 nm	4.51 nm	3.12 nm
Young's Modulus	130 – 170 GPa	5 – 6 GPa	4.7 GPa
Hardness	8.7 GPa	800 MPa	1.15 GPa

Fullerene Derivatives

A range of fullerene derivatives have been investigated for etch behavior. Etch tests on 10 µm patterned strips have been performed to measure the etch rates in silicon etching, compared to a control resist.



Hard Mask Formulation	Carbon Content
HM-110	86.7%
HM-120	84.0%
HM-130	84.0%
HM-140	83.7%

Contrary to expectation as the carbon content is decreased (Ohnishi number is increased), the etch resistance has increased.

Hard Mask Cost

The price of the fullerene derivative dominates the total cost of the hard mask (~98%). However, while the performance (particularly etch resistance) has improved, the cost per gallon has been significantly reduced.
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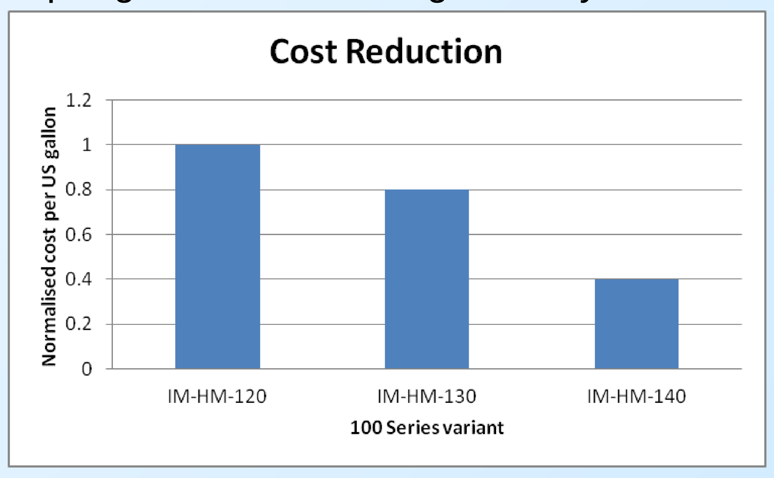
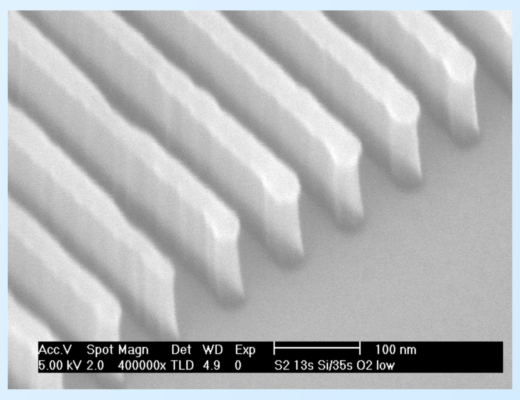
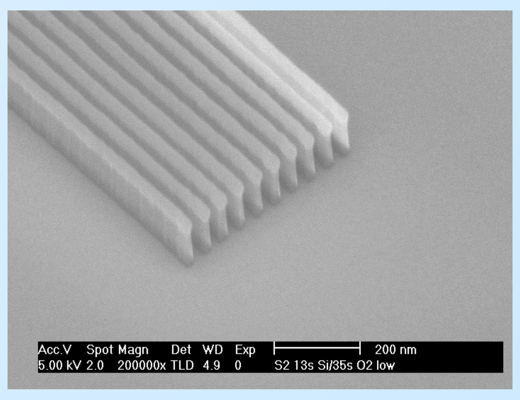


The performance of the material does not suffer as a result of the cost reduction measures.



Sparse 20 nm hard mask features in IM-HM-140



30 nm half pitch patterns in IM-HM-140

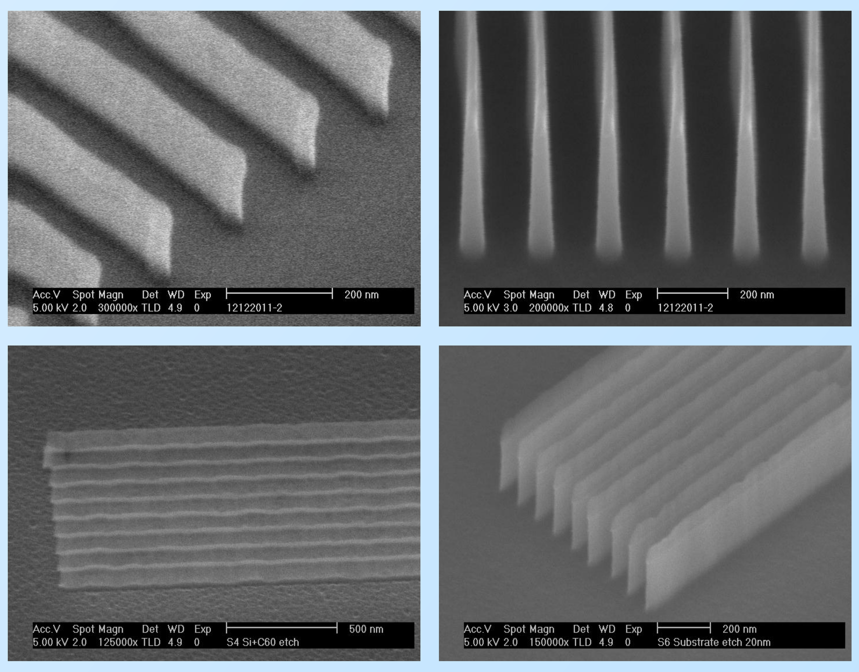
Pattern Transfer I

The material is capable of high-resolution patterning. Sparse line features with a width of 20 nm were successfully etched into silicon as well as 30 nm dense patterns as shown for two of the materials.

Hardmask patterning Silicon etching

IM-HM-110

IM-HM-120

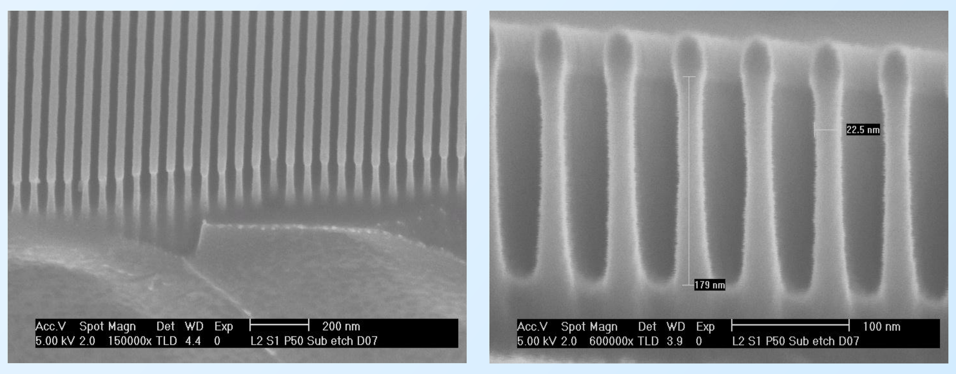


Conditions	
O_2 flow rate (sccm)	10
RF power (W)	150
ICP power (W)	300
Pressure (mT)	2
Temp (°C)	5
Backside He (T)	5

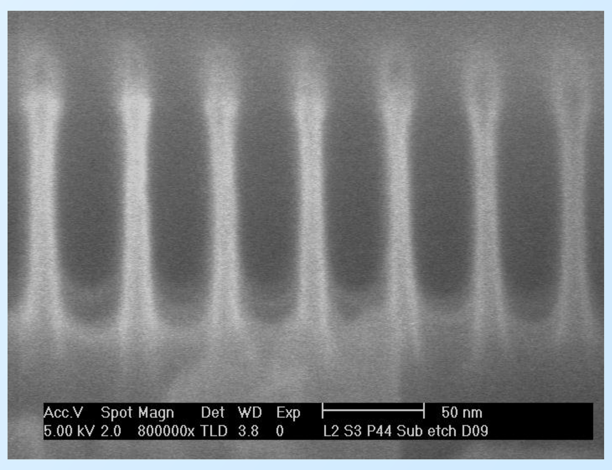
Conditions	
SF_6 flow rate (sccm)	15
CHF_3 flow rate (sccm)	50
RF power (W)	20
ICP power (W)	200
Pressure (mT)	15
Temp (°C)	5
Backside He (T)	10

Pattern Transfer II

Using the extreme ultraviolet interference lithography tool at PSI, Switzerland, an HSQ resist layer was patterned on top of the hard mask stack to produce dense 25 nm half pitch and 12 nm semi dense patterns.



45˚ view and cross section of 25 nm half pitch pattern etched into the silicon substrate



Cross section of 12 nm wide semi dense pattern (~2.5:1) etched into silicon

Summary and Outlook

The use of multilayer hard masks is now essential for the semiconductor industry to produce devices at ever shrinking dimensions, particularly given recent developments in three dimensional device architectures, such as FinFET and Intel trigate devices.

These fullerene based hard mask materials outperform existing state of the art materials across several critical performance metrics, whilst maintaining the advantages of spin-on materials over CVD deposited carbon.

New formulations under development offer:
- further improved thermal stability
- increased etch resistance
- alternative casting solvents

The Irresistible Materials HM-140 hard mask formulation is currently available from MicroChem, a US based supplier of specialist chemicals for microlithographic applications (via a non-exclusive license agreement).

Acknowledgements

The Open University
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